BELLCOMM, INC.
955 L'ENFANT PLAZA NORTH, S.W. WASHINGTON, D.C. 20024

B69 12063

SUBJECT: Effect of Lower CSM Parking Orbit on Rescue After Abort During LM Descent - Case 310

DATE: December 18, 1969

FROM: D. G. Estberg

ABSTRACT

Simulations of CSM rescue of the LM after abort during descent indicate that rescue is feasible for altitudes of CSM lunar parking orbit (ALO) lower than the current value of 60 NM with rendezvous sequences having an elapsed time from abort to completion of crew transfer of about 6 hours. The CSM ΔV required for the rescue depends on when during the descent the abort is made. The most ΔV is required for aborts made during the Hohmann transfer from descent orbit initiation (DOI) to powered descent initiation (PDI); the ΔV requirement for rescue decreases nearly linearly from 225 ft/sec at ALO = 60 NM to 147 ft/sec at ALO = 26.8 NM. Also aborts during the Hohmann transfer impose the lower limit of 26.8 NM on ALO for which rescue is feasible (if an 8-hour rescue sequence is used instead of a 6-hour sequence, the rescue is feasible for ALO down to 16.8 NM). For aborts during powered descent from PDI to touchdown with different LM target orbit apolunes for early and late times of abort, the maximum ΔV required varies between 161 ft/sec and 136 ft/sec for ALO between 60 NM and 26.8 NM. Additional results are given in the memorandum for ALO below 26.8 NM and for other choices of LM target orbit apolune.

In the simulations different rescue sequences were used for aborts during the two different periods of LM descent: a 6-burn sequence for aborts from DOI to PDI and a 5-burn sequence for aborts from PDI to touchdown. For aborts during the first period it was assumed that the LM is non-propulsive after the abort decision, while for aborts during powered descent the rescue is started when the LM has made an ascent to a predetermined orbit after the abort. Both sequences use a phasing orbit to obtain the correct LM-CSM phasing needed to start the standard coelliptic rendezvous sequence.

CONTENTS

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MEMORANDUM FOR FILE

I. INTRODUCTION

In order to increase the Lunar Module (LM) landed payload capability, it has been proposed [1]* that the Command and Service Module (CSM) lunar parking orbit altitude be lowered. Such a decrease changes the phasing between the LM and the CSM after separation and hence changes the rendezvous required in the case of an abort during LM descent. If the LM becomes inactive after the abort, CSM active rendezvous is required for rescue. For altitudes of CSM lunar parking orbit (ALO) lower than the present value of 60 NM, CSM rescue has not been sufficiently studied.

Results of computer simulations of CSM rescue after abort during LM descent for lower ALO are presented in this memorandum.** The quantities of interest from these simulations are the CSM characteristic velocity (ΔV) required to perform the rendezvous and the elapsed time from abort to completion of crew transfer. ALO was varied parametrically; the lowest value used was ALO = 50,000 ft, the altitude of powered descent initiation (PDI). Also the number of revolutions used for the rendezvous was varied in order to get an indication of the trade off between ΔV required and elapsed time of the rendezvous. For aborts after PDI two additional parameters were varied: time of abort initiation and apolune altitude of the orbit achieved by the LM after abort. In addition, the optimum LM orbit apolune (minimum required CSM ΔV) was determined.

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*Brackets, [ ], enclose reference numbers.

**The operational aspects of CSM active rendezvous after nominal ascent for lower ALO will be considered in another Bellcomm memorandum [3]; propellant requirements for rendezvous after nominal ascent are less than for rendezvous after abort during descent.

II. THE ABORT AND RESCUE SEQUENCES

Two different rescue sequences were used in the simulations described in this memorandum. One is applicable for aborts occurring when the LM is in the Hohmann transfer orbit from descent orbit initiation (DOI) to PDI, including the case where PDI cannot be performed; it is assumed that the LM is nonpropulsive after the abort decision. The other is for aborts after PDI. In this case, the rescue is started when the LM has made an ascent to a predetermined safe orbit after the abort. The CSM rescue sequence used for abort during Hohmann transfer is a 6-burn sequence, while the sequence used for abort during powered descent has 5 burns and is referred to as the rescue 2 sequence.* For both sequences the rescue is from above and ahead. The last 3 burns of both sequences are part of the coelliptic rendezvous sequence, the standard sequence that has been used in the Apollo program for the final phases of rendezvous. Constraints on the rescue sequences and assumptions used in their simulation are summarized in Appendix A.

The first burns of both sequences are used to establish the CSM-LM phase angle and differential height required to start the coelliptic rendezvous sequence. The first three burns of the CSM 6-burn rescue sequence used after abort from Hohmann transfer are shown in Figure 1. If an abort decision is made at any time during the Hohmann transfer, the first burn of the rescue sequence is made at the nominal time of PDI + 10 min. This burn puts the CSM into a transfer orbit, and the second burn, a half revolution later, circularizes the CSM in an orbit with altitude such that phasing will be correct. After 11/12 or 1-11/12 revolutions in this phasing orbit, the coelliptic sequence initiation (CSI) burn is performed on the line of apsides of the LM orbit in order to establish the correct differential height to start the coelliptic rendezvous sequence.

The first two burns of the CSM rescue 2 rendezvous sequence used after abort during powered descent are shown in Figure 2. The first CSM burn of this sequence (the rescue 2 burn), which occurs about half a revolution after LM orbit insertion upon crossing of the LM line of apsides (i.e., on the back side of the moon), puts the CSM in a transfer orbit that transfers the CSM from the lunar parking orbit

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*It derived its name from the name of the first burn, which is called the rescue 2 burn because it used to be the second burn in the 6-burn CSM rescue sequence previously used by MSC [4].

and also establishes the correct differential height to start the coelliptic rendezvous sequence. The CSI burn, the second burn, puts the CSM into an orbit to establish phasing. For both sequences the minimum altitude of the phasing orbit allowed was 50,000 ft in order to maintain a prescribed clear perilune.

The coelliptic rendezvous sequence as it is used to complete the above sequences is shown in Figure 3. The constant differential height (CDH) burn puts the CSM into an orbit that is coelliptic to the LM orbit; that is, the CSM orbit has the same line of apsides as the LM orbit and has fixed differential height above the LM orbit at perilune and apolune. The terminal phase initiation (TPI) burn changes the orbit such that the CSM will rendezvous with the LM and certain constraints, such as lighting, are met. Terminal phase finalization (TPF) is a series of manual braking burns used to reduce the relative velocity between the LM and the CSM to zero; it is represented in the figure as a single burn. In order to estimate the duration of the rescue, it was assumed that the elapsed time from TPI to completion of crew transfer is 1.5 hr [4].

The LM ascent after aborting from powered descent is very similar to the nominal LM ascent. The descent engine is used at the fixed throttle point with the guidance the same as for the nominal ascent. For abort after about PDI + 5 min, staging is required because of descent propellant depletion. The ascent engine continues the ascent to orbit. For this study orbit insertion, at 60,000 ft, was made at perilune, and the apolune was used as a parameter, taking on values from 60,000 ft to 100 NM.

III. CSM ΔV REQUIREMENTS FOR RESCUE AFTER ABORT DURING HOHMANN TRANSFER

Figure 4 shows that the CSM ΔV requirement for an 8-hour rescue (two revolutions in phasing orbit) after abort during Hohmann transfer decreases from about 200 ft/sec to about 100 ft/sec as ALO is decreased from 60 NM to 16.8 NM. Since the ΔV required for a 6-hour rescue (one revolution in phasing orbit) is only about 20 ft/sec greater than this, the 6-hour rescue seems preferable for ALO down to 26.8 NM. The lower limit on the applicability of these sequences is caused by the 50,000 ft minimum on altitude of the phasing orbit. Increasing the number of revolutions in phasing orbit above two does not substantially decrease the lower limit on ALO. Except for abort before DOI + 10 min when a direct rendezvous is used, the same abort sequence is used for all aborts during Hohmann transfer. Therefore, the elapsed time from abort to completion of crew transfer for aborts earlier than PDI can be up to about 50 min longer than for aborts at PDI. What is here called an 8-hour rescue has a duration of 7.6 hr for abort at PDI and 8.4 hr for abort at DOI + 10 min; a 6-hour rescue has a duration of 5.8 hr for abort at PDI and 6.6 hr for abort at DOI + 10 min.

IV. CSM ΔV REQUIREMENTS FOR RESCUE AFTER ABORT DURING POWERED DESCENT

Variation of CSM ΔV with Lunar Parking Orbit Altitude, Time of Abort and LM Target Orbit Apolune

Figures 5 through 9 are contour maps showing the variation in the CSM ΔV requirement with ALO for all times of abort after PDI + 54 sec and for various LM target orbit dimensions (60,000 ft circular, 60,000 ft x 30 NM, 60,000 ft x 50 NM, 60,000 ft x 70 NM and 60,000 ft x 100 NM) for the rescue 2 rendezvous after abort from powered descent. The duration of the rendezvous from abort to completion of crew transfer varies from 5.69 to 6.00 hr; this time variation is mostly due to variation of target orbit apolune, is slightly due to variation of time of abort and is nearly independent of ALO. For all except high LM target orbits, there are some ALO and times of abort such that the rescue 2 rendezvous will not work because the CSM perilune in the phasing orbit falls below 50,000 ft (shown by the shaded areas in the figures). For low LM target orbits, CSM rescue is possible only for low ALO and late times of abort.

Considering a fixed LM target orbit, the ΔV surface has a trough in the ALO/time-of-abort plane with minimums as low as 40 ft/sec and sides rising to above 550 ft/sec. For high LM target orbits, the trough minimum crosses the plane at high ALO and early times of abort. As the LM target orbit is lowered, the trough moves toward low ALO and late times of abort. In the figures two dashed lines, which denote discontinuities in the derivative of the ΔV surface, define the bottom of the trough. The trough has a horizontal flat bottom between the intersection of these lines and the intersection of the trough with another discontinuity in the derivative at ALO = 19.9 NM. The remainder of the trough on either end still has a flat bottom but it slopes up. Briefly the reason for the existence of the trough in the ΔV surface is that for a certain CSM-LM phase at LM orbit insertion the ΔV required to rendezvous is a minimum because little or no burn is required to get into the phasing orbit. For CSM-LM phases ahead or behind this, a higher or lower phasing orbit is required to obtain the correct phasing. Further discussion of this point, including the reason why there are discontinuities in the derivative of the ΔV surface, is given in Appendix B.

ΔV Optimization with Respect to Apolune of LM Target Orbit

Three ways of determining the best LM target orbit apolune were considered. First, if it is desired to use the absolute minimum CSM ΔV for the rescue, then for each ALO and each time of abort a LM target orbit apolune can be found such that the ΔV is minimum. This results in a LM target orbit apolune that varies with time of abort (on the Apollo 11 mission a variable LM target orbit was used to obtain phasing rather than to minimize ΔV). Secondly, if it is desired to have a single LM target orbit that will work for all times of abort while still keeping the ΔV as low as possible, then for each ALO a LM target orbit apolune can be found such that the ΔV is minimum. Because of the trough that exists in the ΔV surface of Figures 5 through 9, the target orbit apolune is chosen such that the ΔV required will be the same for early and late times of abort and less for intermediate times. Finally, a compromise between having the absolute minimum ΔV and having the simplicity of only one LM target orbit is to have two different LM target orbits, one for early and one for late times of abort. This is the procedure that was once planned for the Apollo 11 mission before a variable target orbit was introduced. For each ALO, a time of abort dividing the early and late abort regions and two target orbit apolunes are chosen such that the ΔV is minimum. In determining the target orbit apolune for all three methods, the optimum value was found such that two constraints were satisfied: the LM target orbit apolune was to be above 60,000 ft and the perilune of the CSM phasing orbit was to be above 50,000 ft.

The results of carrying out the above three methods of optimization are shown in Figures 10 through 12. Two sets of contour lines show the CSM ΔV required along with the necessary LM target orbit apolune for all ALO and times of abort. In order to summarize and compare the ΔV requirements for these three methods, the maximum requirement considering all times of abort is plotted in Figure 13 for each method; this maximum occurs at the latest time of abort considered except in the first method for high ALO when the maximum occurs at the earliest time of abort considered. For full optimization with a variable target orbit, the ΔV requirement decreases from 155 ft/sec to 106 ft/sec as ALO is decreased from 60 NM to 33.5 NM, then increases to 278 ft/sec as ALO is further decreased to 50,000 ft; the reason for this increase for low ALO is that the optimum target orbit apolune would be below 60,000 ft, so 60,000 ft was used. When optimization is carried out for the case where there is only one target orbit for all times of abort, ΔV requirements are approximately doubled. For this case as ALO decreases below 48.3 NM the ΔV requirement increases because a lower, more optimum target orbit apolune would make the phasing orbit perilune below 50,000 ft for some times of abort. When optimization is carried out with different target orbit apolunes for early and late times of abort, the resulting ΔV requirement is not more than 30% higher than full optimization with a variable target orbit. In fact for ALO below 28.3 NM the maximum ΔV requirement is the same because target orbit apolune was set at 60,000 ft. Between 28.3 NM and 35.9 NM, the 50,000 ft minimum on the phasing orbit perilune is the limiting parameter as in the case of one target orbit for all times of abort.*

Variation of CSM ΔV with Number of Revolutions Used for Rescue

According to [4] the ascent stage lifetime for a fully powered up LM is about 7.5 to 8 hr; by powering down the lifetime can be extended to about 12 hr. Therefore, it is possible to have a rescue with a duration longer than 6 hr and to reduce the ΔV required for rescue. In order to get an indication of how much the ΔV requirement would be reduced, simulations were carried out for 2, 3 and 5 revolutions in phasing orbit with ALO = 50,000 ft and a LM target orbit apolune of 100 NM. The top curve in Figure 14 for one revolution in phasing orbit (duration 6 hr) is taken from Figure 9 for ALO = 50,000 ft. The other curves show that by adding one more phasing revolution a significant amount of ΔV can be saved (about 30%), but the savings resulting from adding more revolutions after that are not as significant. The ΔV saved for higher ALO is not as great as for lower ALO.

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*Reference 4 indicates that the minimum allowed LM target orbit apolune for Apollo 11 was 30 NM. If this constraint were imposed rather than 60,000 ft, the ΔV requirements for all three methods of optimization would be increased. For the case of one apolune for all times of abort the increase would be less than 10% and only for ALO less than 16.5 NM. For the other methods of optimization there would be no increase for ALO down to 40 or 50 NM and below that the increase would be up to 35% for ALO = 50,000 ft.

V. SUMMARY AND CONCLUSIONS

Computer simulations of CSM rescue after abort during LM descent have shown that there exist 6-hour rescue sequences that can be used for ALO down to 26.8 NM. The CSM ΔV requirements for these rescues are summarized in Figures 4 and 13.

For LM abort during the first part of descent, the Hohmann transfer from DOI to PDI, the ΔV requirement for rescue decreases nearly linearly from 225 ft/sec at ALO = 60 NM to 147 ft/sec at ALO = 26.8 NM. The 6-hour rescue sequence used in this memorandum cannot be used for ALO below 26.8 NM because the minimum altitude of the CSM orbits during rescue would be below 50,000 ft. An 8-hour rescue sequence could be used for ALO down to 16.8 NM, and the ΔV requirements would be about 20 ft/sec below the 6-hour rescue values.

The ΔV requirement for rescue after abort during LM powered descent from PDI to landing depends on how the LM target orbit after abort is chosen. If only one target orbit is used for all times of abort, the ΔV requirement decreases from 250 ft/sec at ALO = 60 NM to 240 ft/sec at ALO = 48.3 NM, then increases to 325 ft/sec at ALO = 50,000 ft. If different LM target orbits are used for early and late times of abort, the ΔV requirement decreases from 161 ft/sec at ALO = 60 NM to 136 ft/sec at ALO = 35.9 NM, remains about constant to ALO = 28.3 NM, then increases to 278 ft/sec at ALO = 50,000 ft. If a variable LM target orbit is used depending on the time of abort, then the ΔV requirement decreases from 155 ft/sec at ALO = 60 NM to 106 ft/sec at 33.5 NM, then increases to 278 ft/sec at ALO = 50,000 ft. If an 8-hour rescue sequence is used instead of a 6-hour sequence, the ΔV requirements can be reduced slightly (about 30% for ALO = 50,000 ft).

D. G. Estberg

2013-DGE-srb D. G. Estberg

Attachments:
- Figures
- Appendices
- Figures for the Appendices
- References

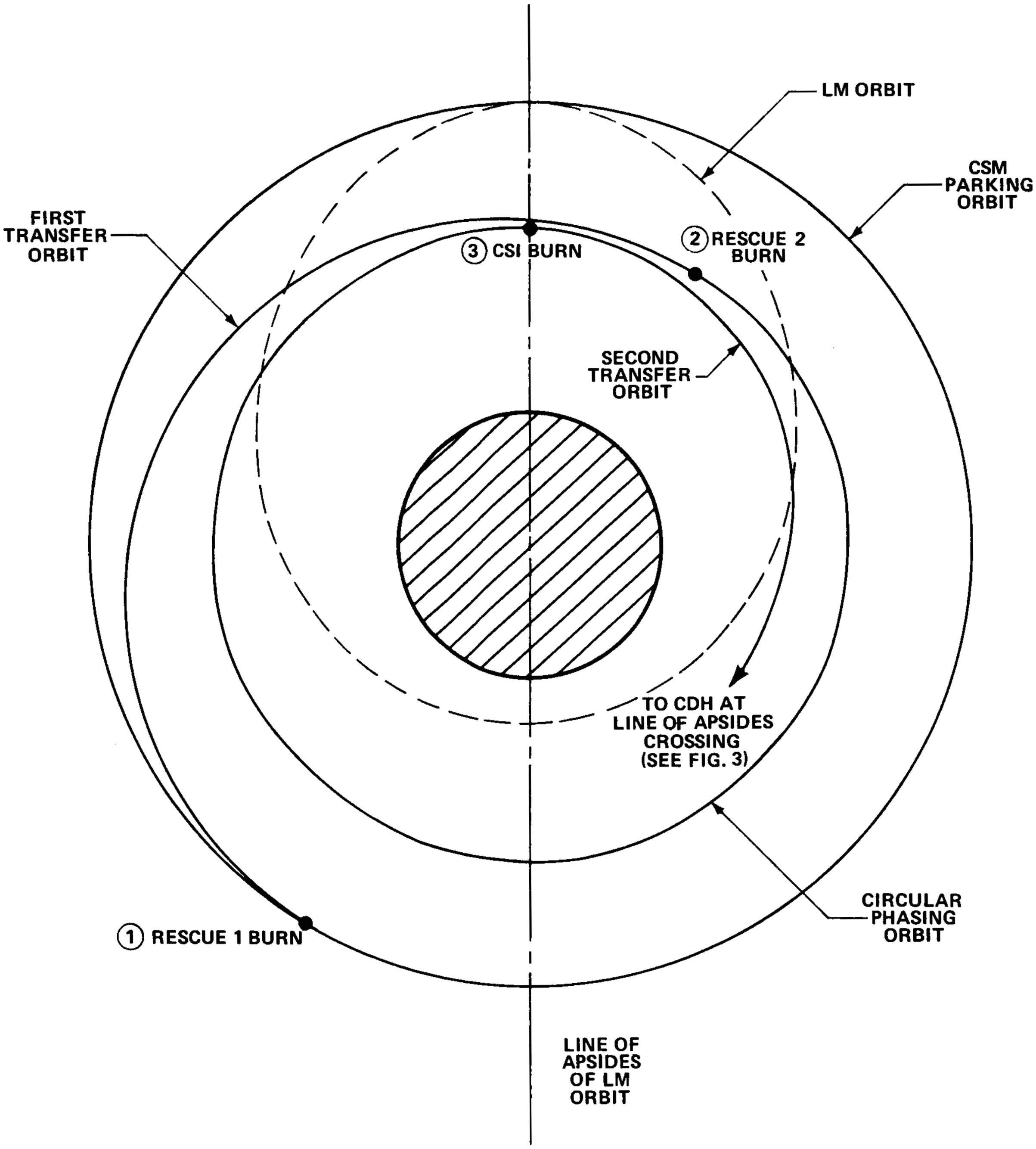

FIGURE 1 - FIRST THREE BURNS OF THE CSM RESCUE SEQUENCE
USED AFTER ABORT FROM HOHMANN TRANSFER

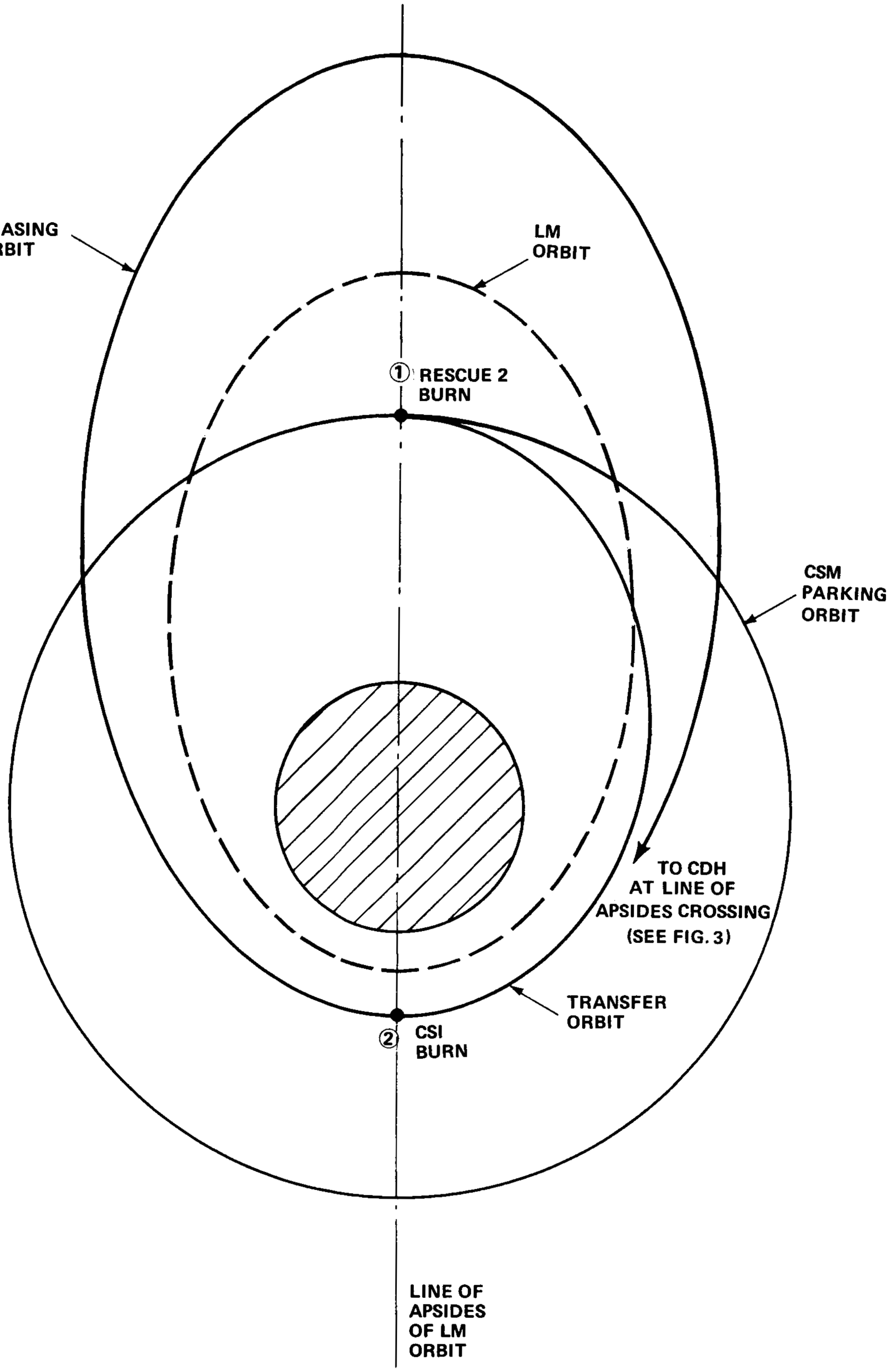

FIGURE 2 - FIRST TWO BURNS OF THE CSM RESCUE 2 RENDEZVOUS SEQUENCE
USED AFTER ABORT FROM POWERED DESCENT

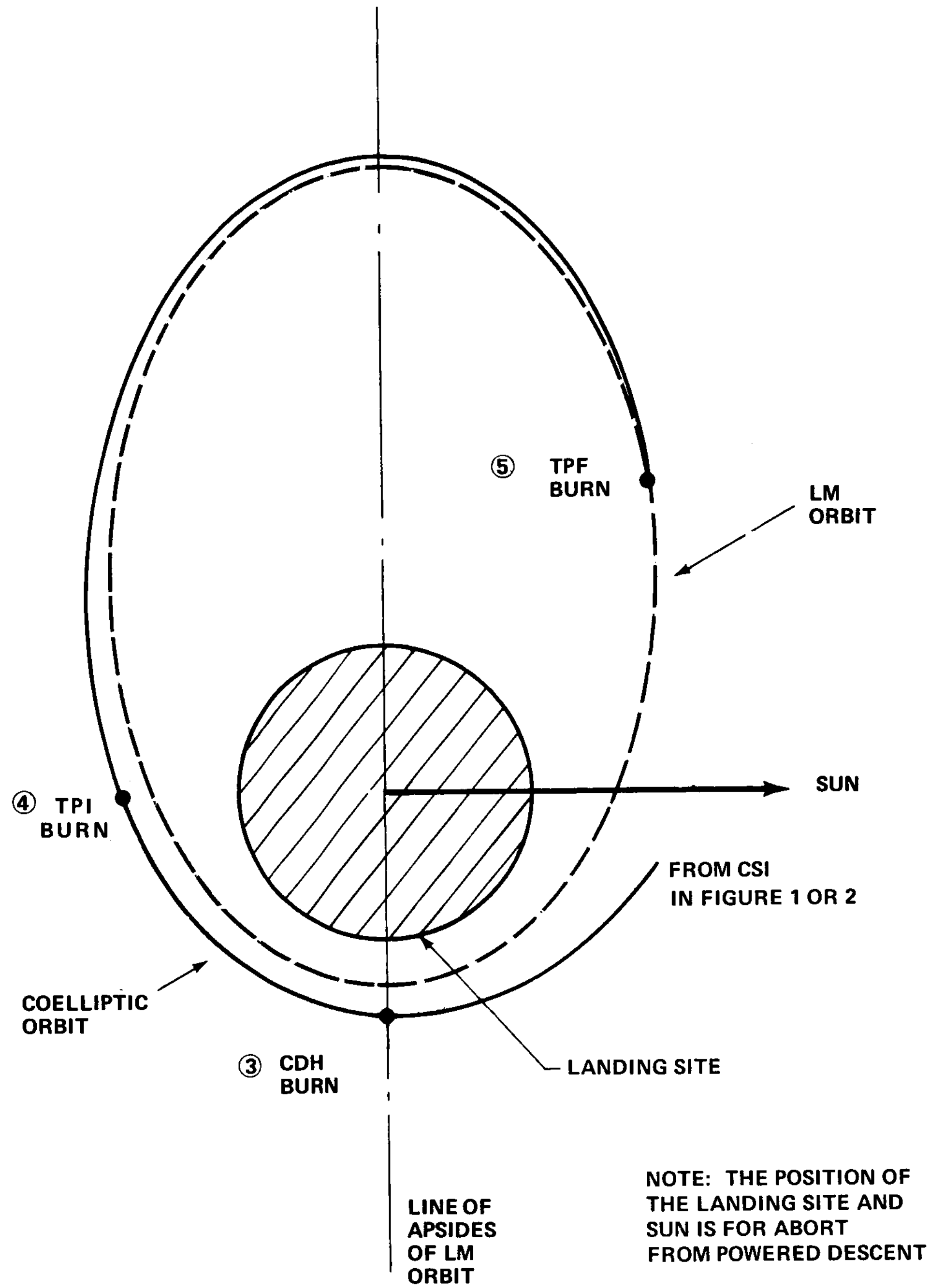

FIGURE 3 - THE COELLIPTIC RENDEZVOUS SEQUENCE

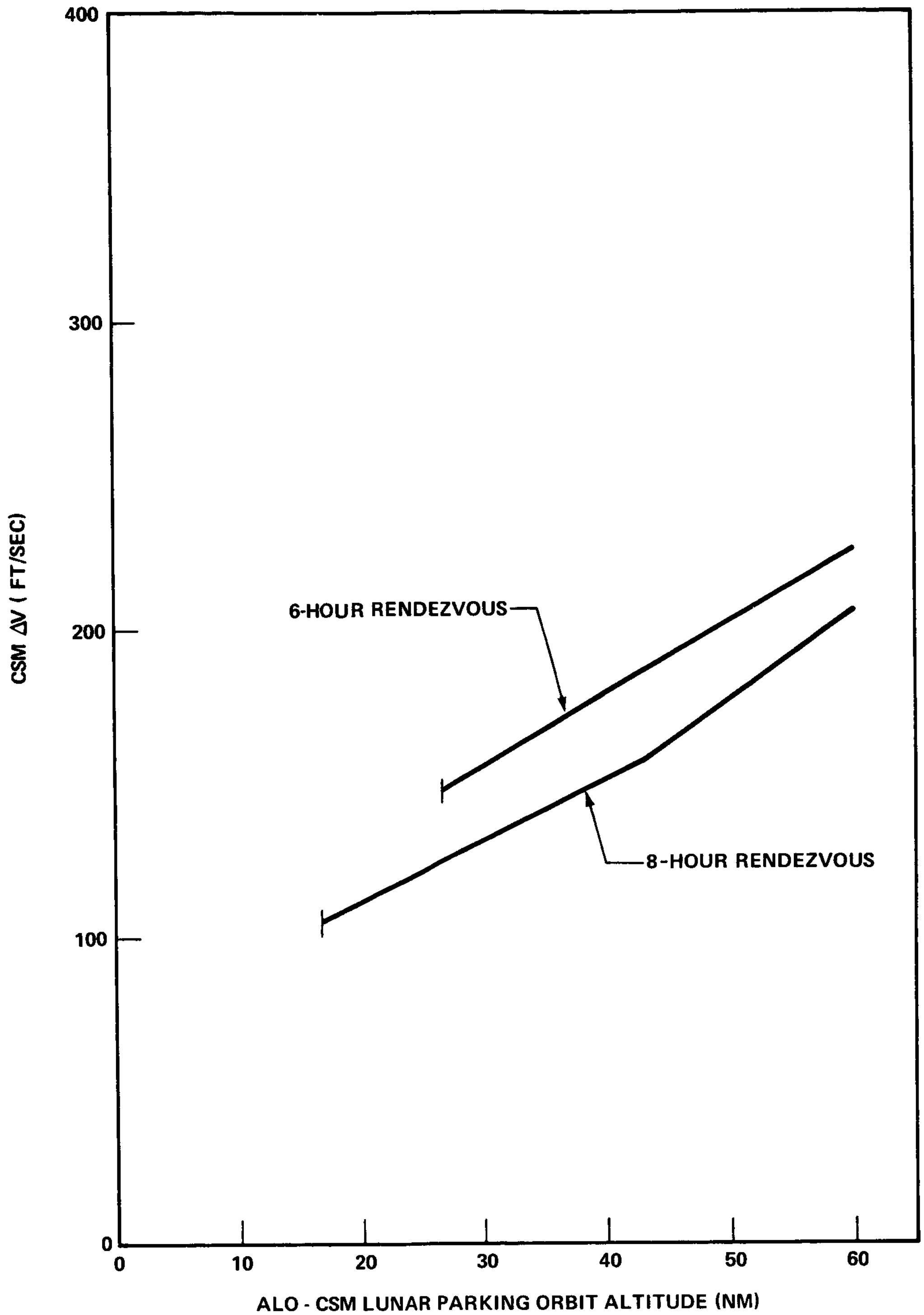

FIGURE 4 - ΔV REQUIRED FOR THE CSM 6 - BURN RESCUE
USED AFTER ABORT FROM HOHMANN TRANSFER

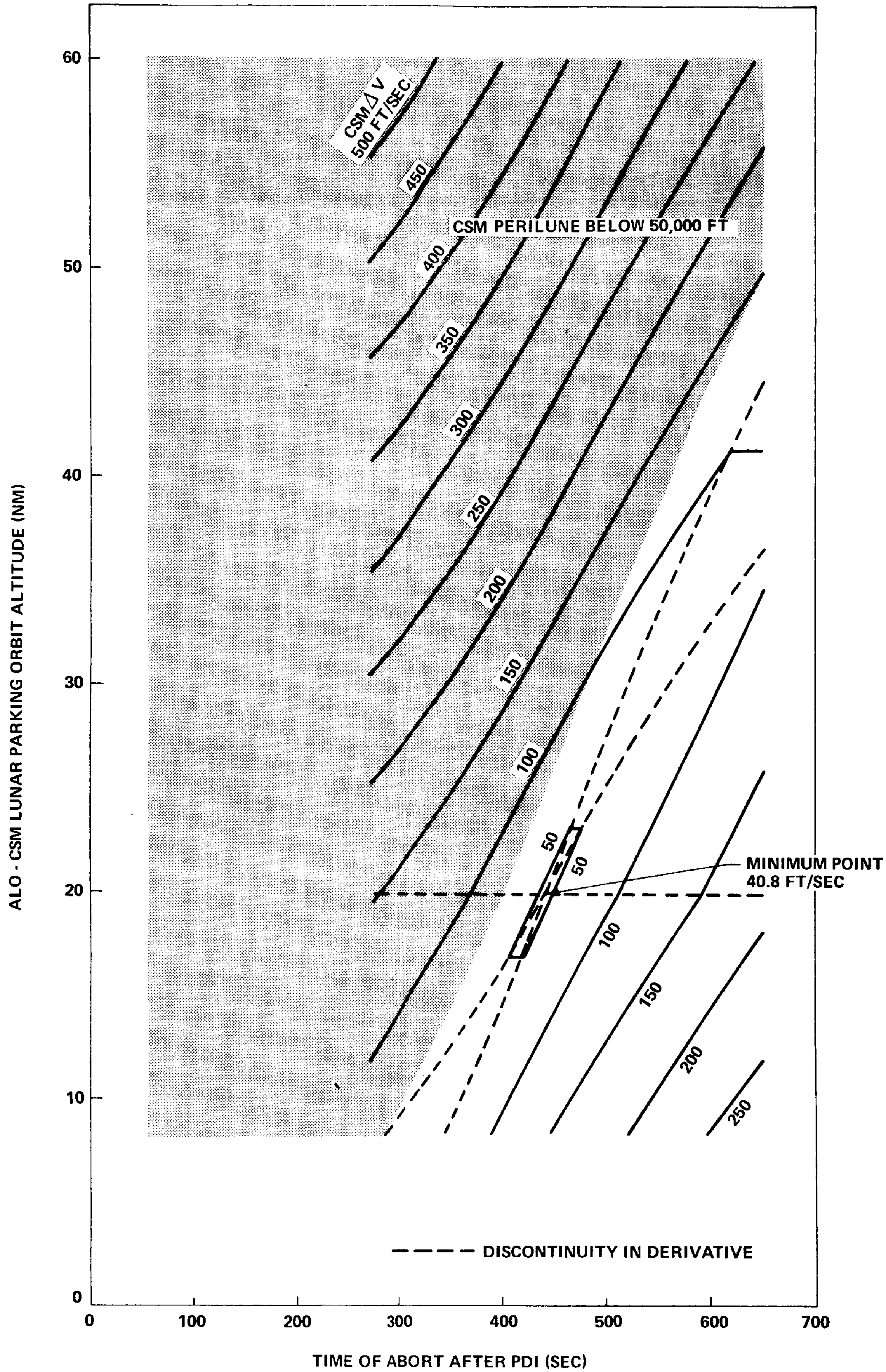

FIGURE 5 - ΔV REQUIRED FOR CSM RESCUE 2 RENDEZVOUS
LM TARGET ORBIT 60,000 FT CIRCULAR

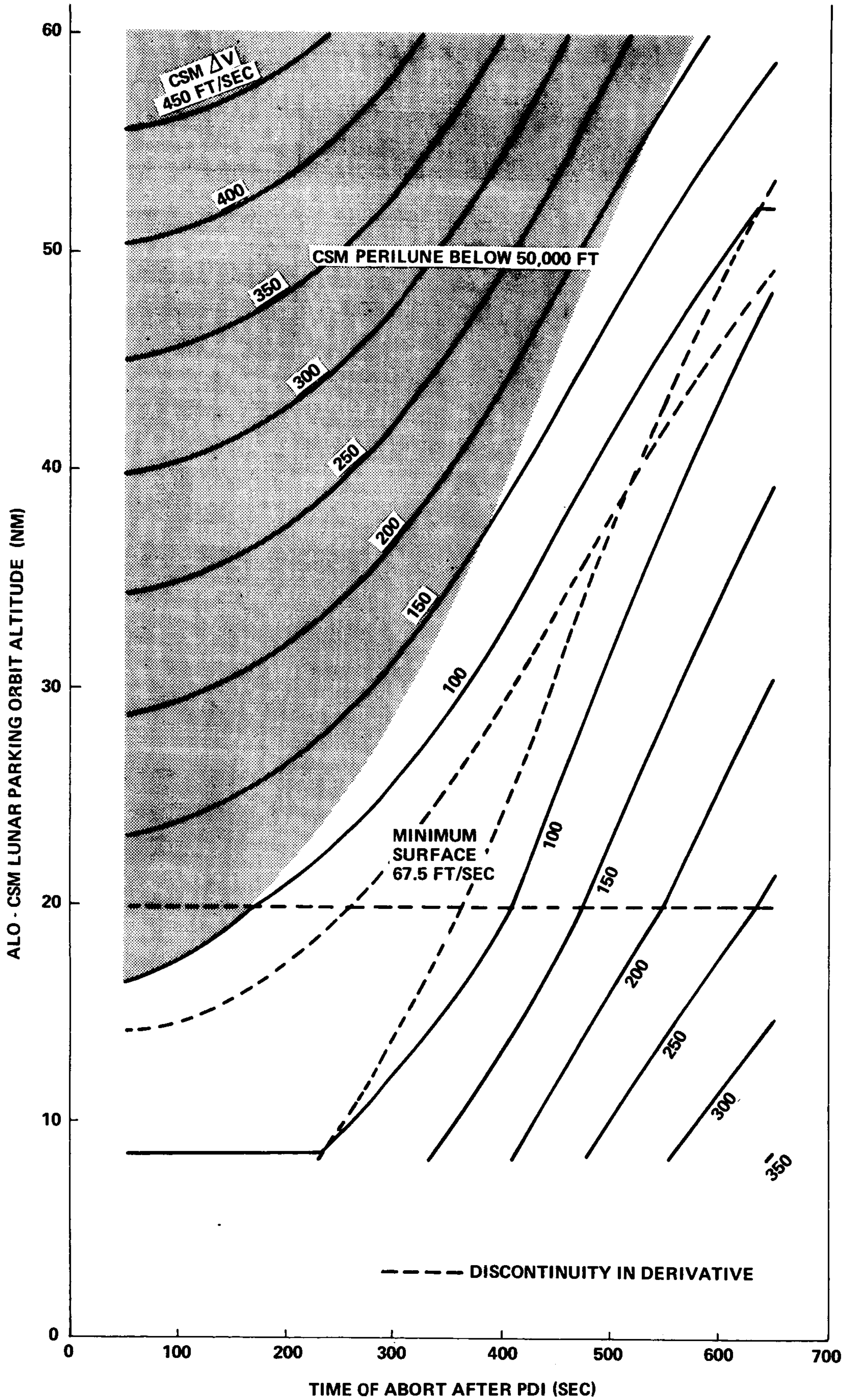

FIGURE 6 - ΔV REQUIRED FOR CSM RESCUE 2 RENDEZVOUS
LM TARGET ORBIT 60,000 FT x 30 NM

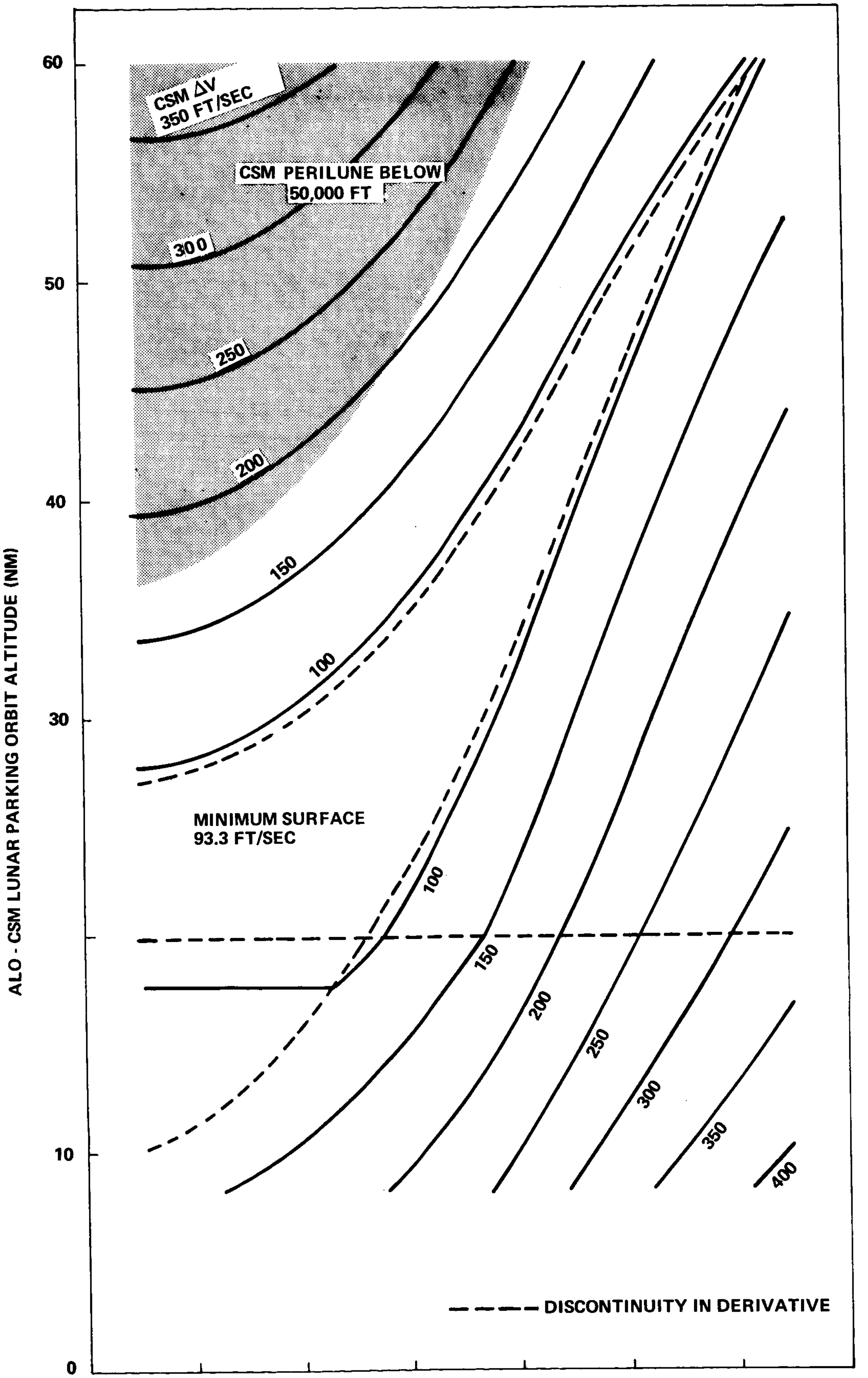

FIGURE 7- ΔV REQUIRED FOR CSM RESCUE 2 RENDEZVOUS
LM TARGET ORBIT 60,000 FT x 50NM

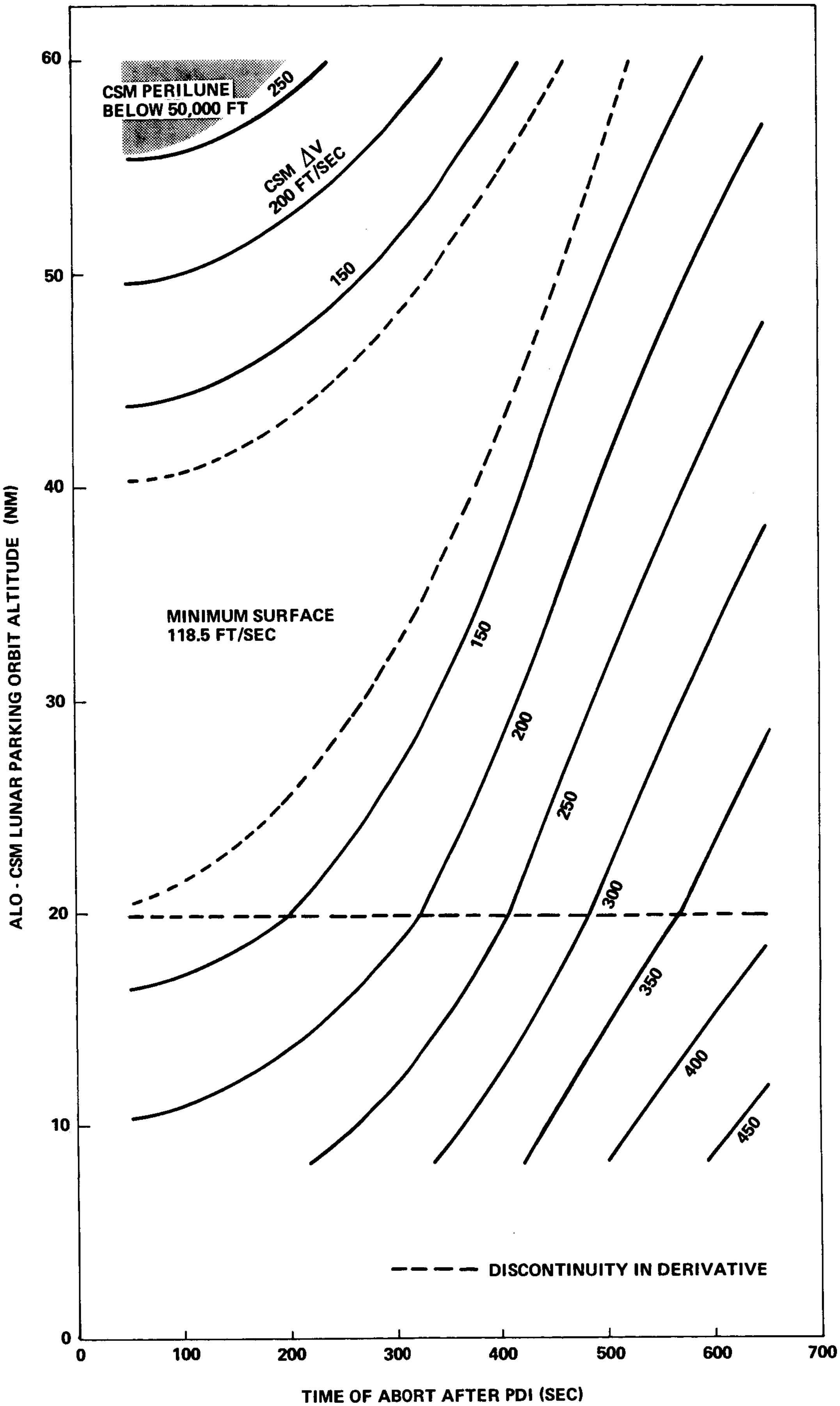

FIGURE 8 - ΔV REQUIRED FOR CSM RESQUE 2 RENDEVOUS
LM TARGET ORBIT 60,000 FT x 70 NM

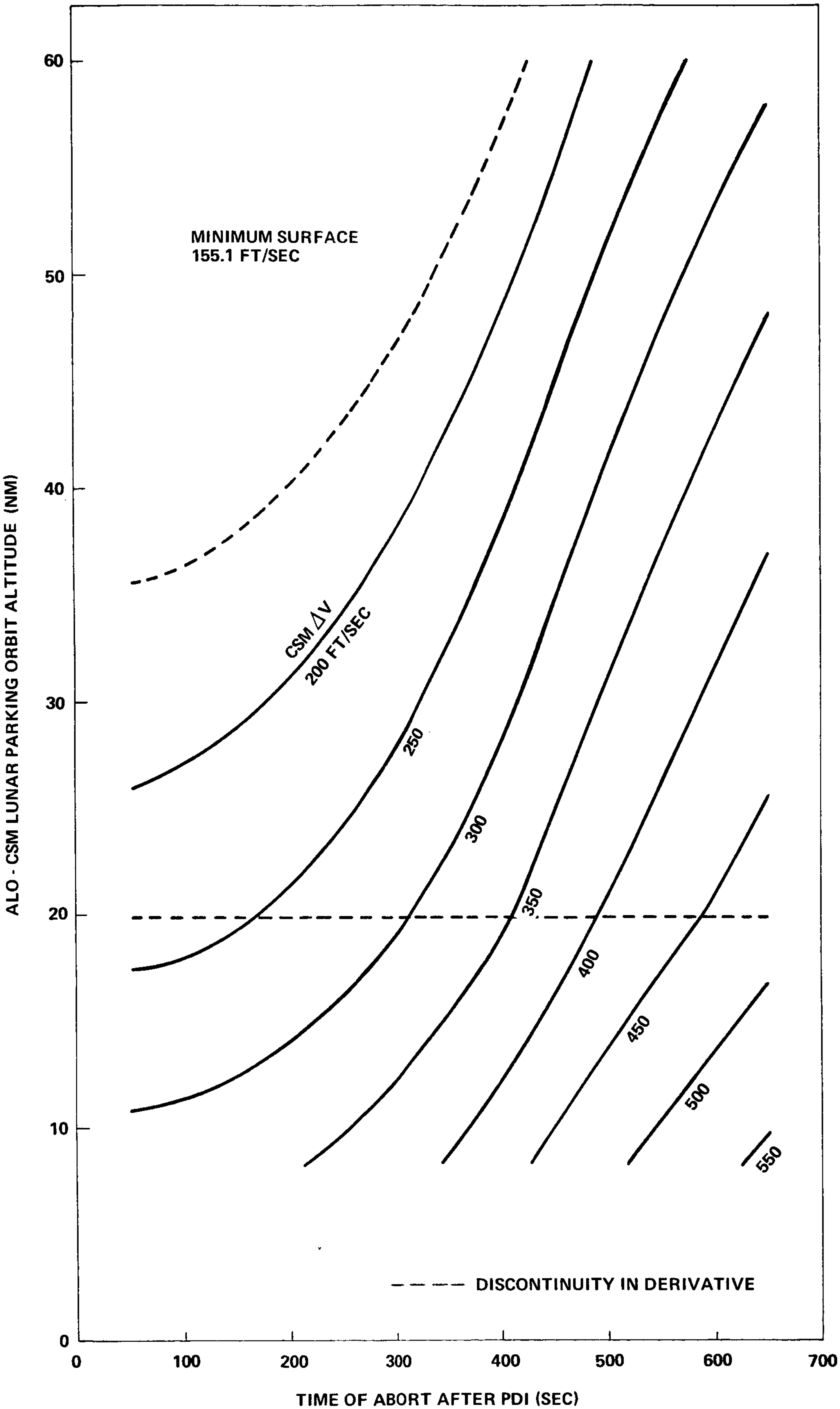

FIGURE 9 - ΔV REQUIRED FOR CSM RESCUE 2 RENDEZVOUS
LM TARGET ORBIT 60,000 FT x 100 NM

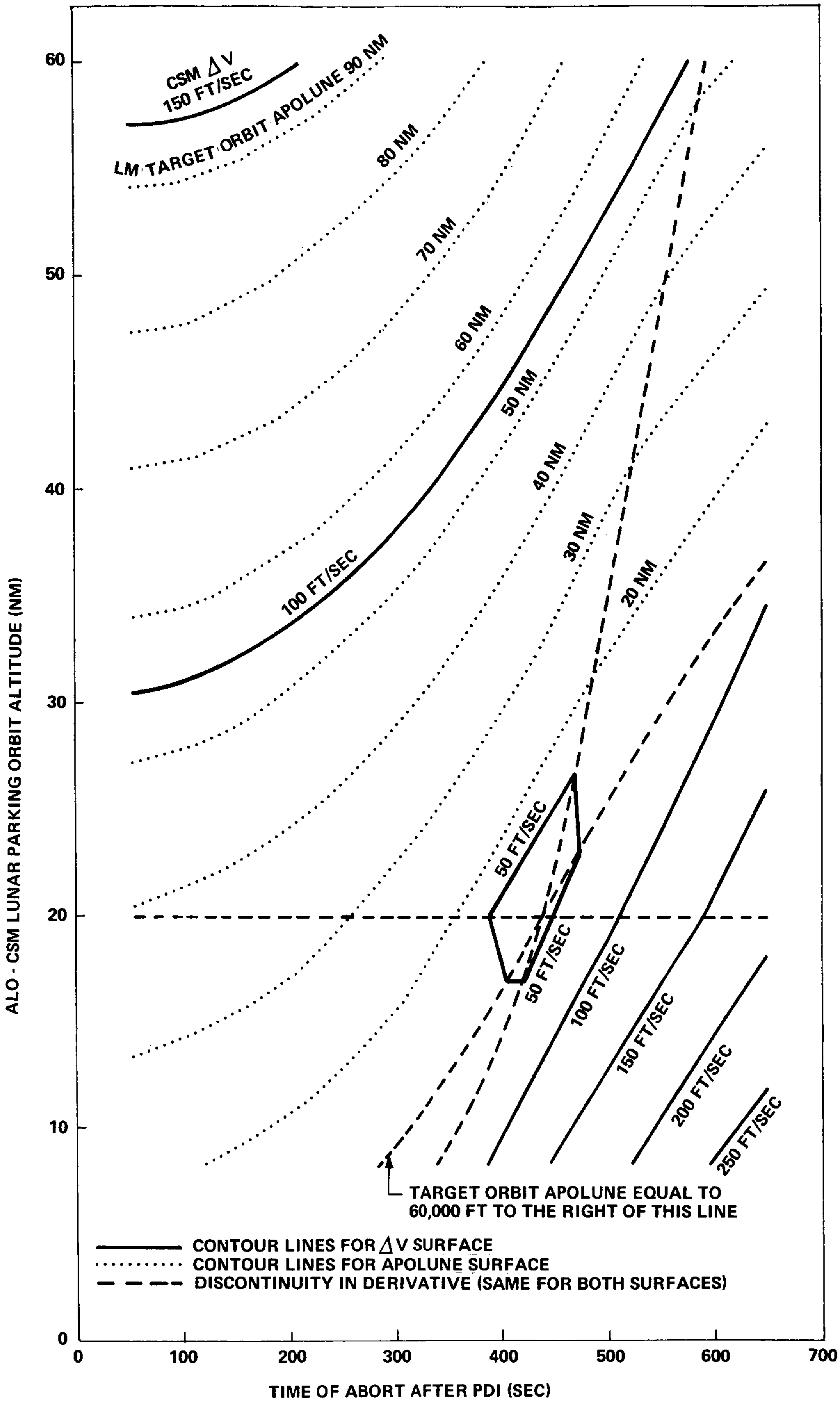

FIGURE 10 - ΔV REQUIRED FOR CSM RESCUE 2 RENDEZVOUS
OPTIMUM VARIABLE LM TARGET ORBIT APOLUNE

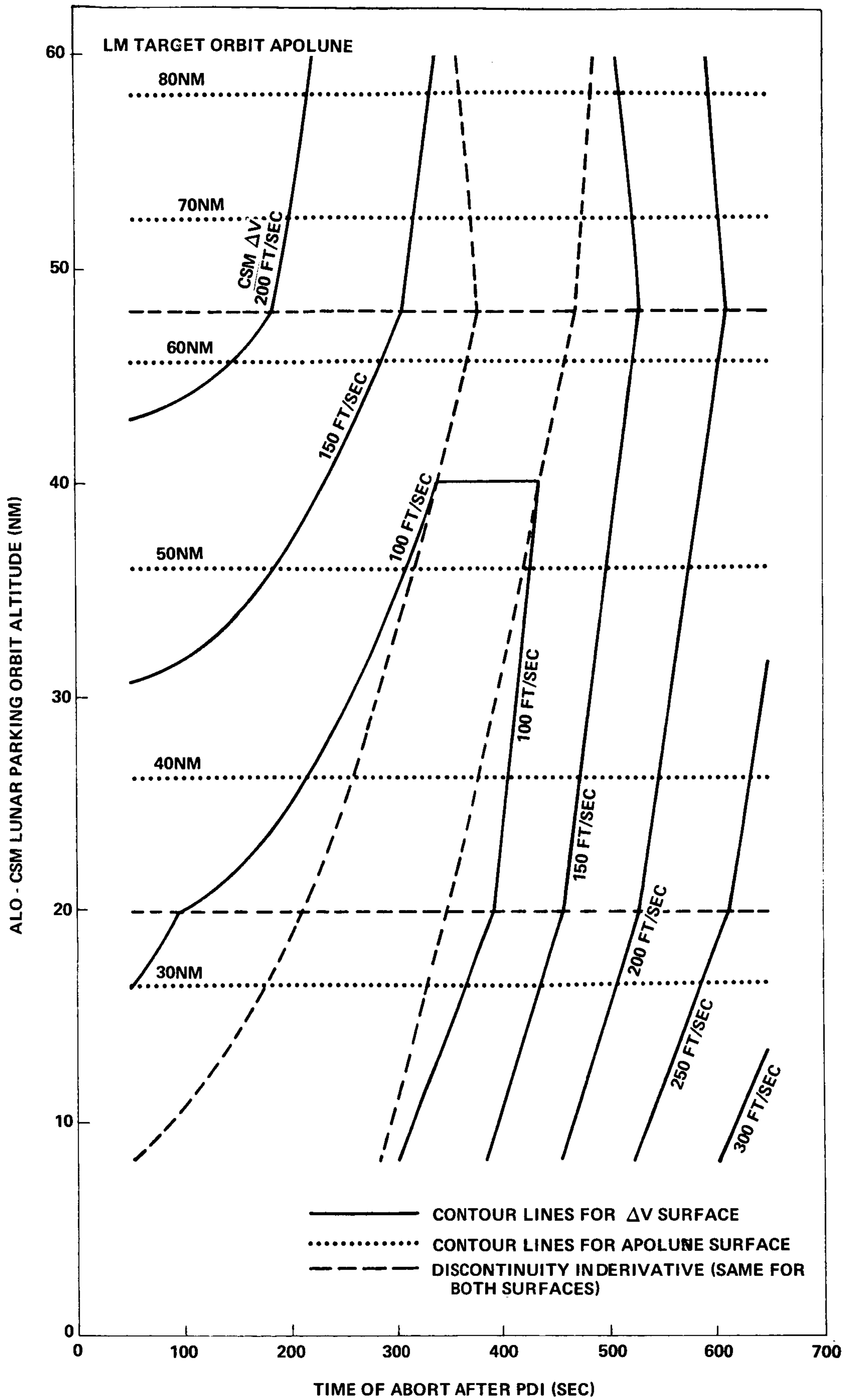

FIGURE 11 - ΔV REQUIRED FOR CSM RESCUE 2 RENDEZVOUS OPTIMUM LM TARGET ORBIT APOLUNE WITH ONE APOLUNE FOR ALL TIMES OF ABORT

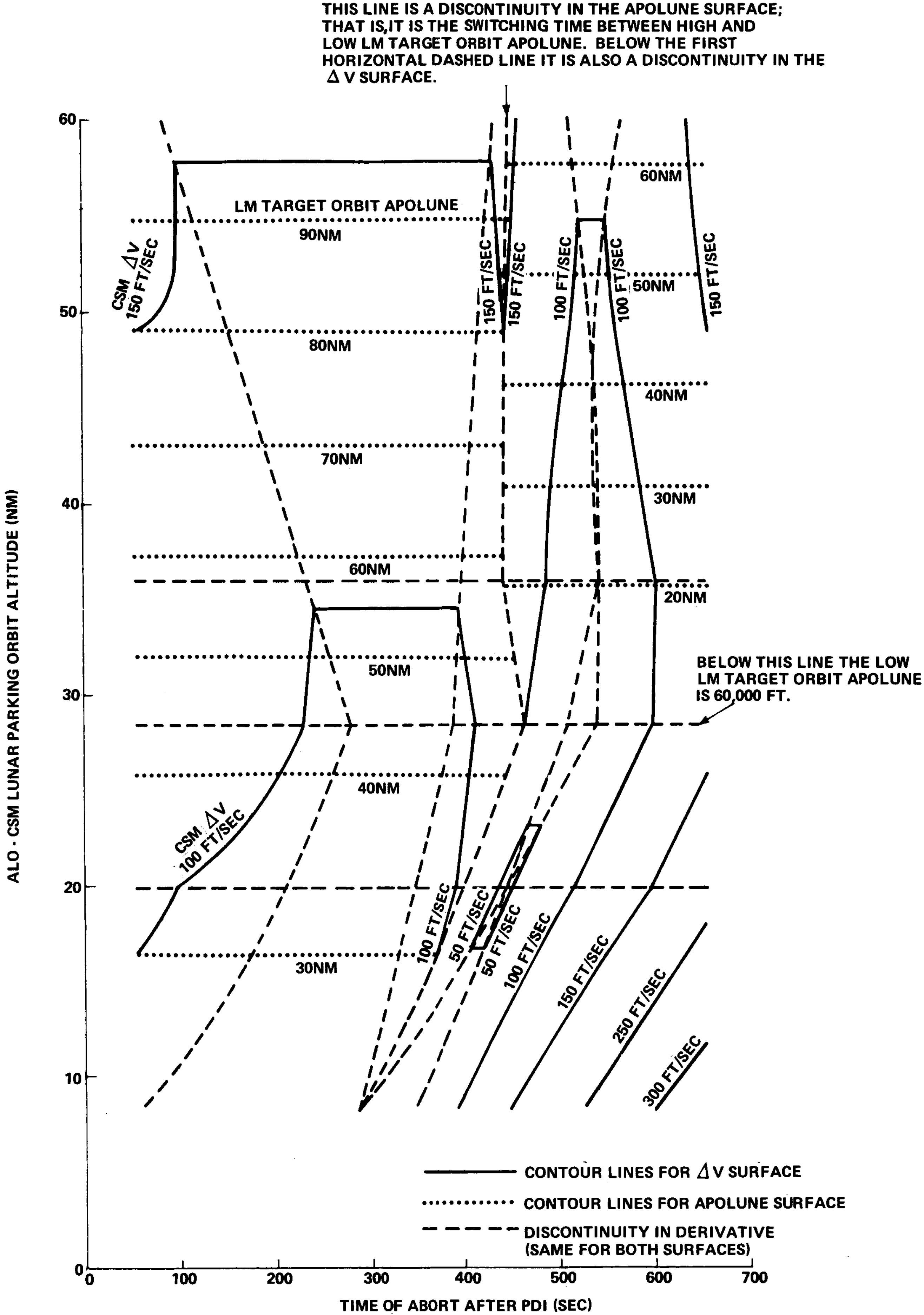

FIGURE 12 - ΔV REQUIRED FOR CSM RESCUE 2 RENDEZVOUS OPTIMUM LM TARGET ORBIT APOLUNE WITH DIFFERENT APOLUNES FOR EARLY AND LATE TIMES OF ABORT

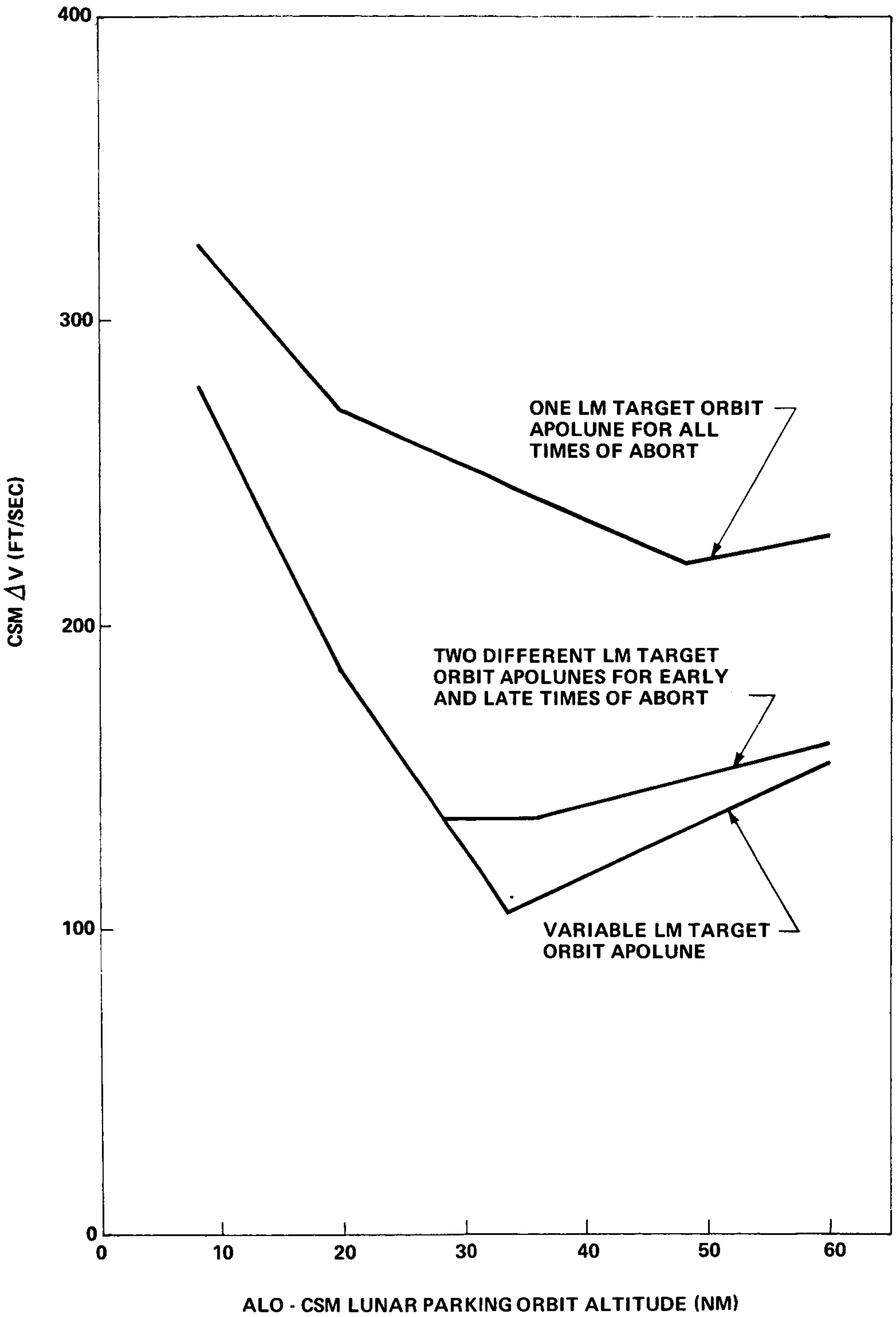

FIGURE 13 - MAXIMUM ΔV REQUIRED FOR THE CSM RESCUE 2 RENDEZVOUS USED AFTER ABORT FROM POWERED DESCENT

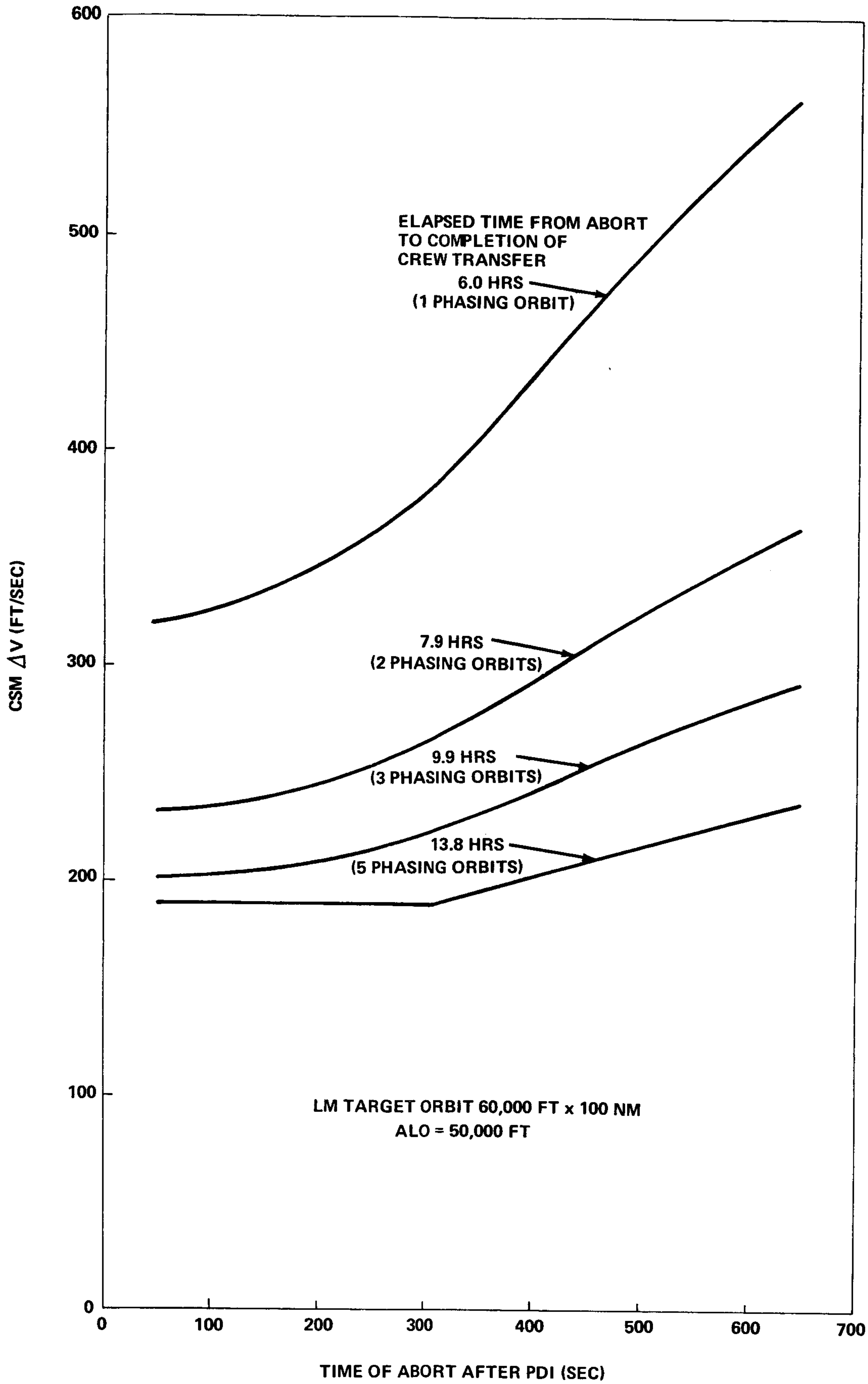

FIGURE 14 - ΔV REQUIRED FOR CSM RESCUE 2 RENDEZVOUS WITH 1, 2, 3 AND 5 PHASING ORBITS

APPENDIX A

CONSTRAINTS AND ASSUMPTIONS

Constraints on the Rendezvous

Minimum CSM perilune	50,000 ft
Differential height at CDH	10 NM
Position of TPI	Midpoint of darkness
TPI burn direction	Line-of-sight
LM transfer angle from TPI to TPF	130°

Initial Conditions

LM state vector at abort	Taken from [2]
LM target orbit insertion altitude	60,000 ft
LM target orbit insertion radial rate	0 ft/sec

Spacecraft Data

LM weight at LM-CSM separation	33,055. lb
LM weight at abort (unstaged)	Taken from [2]
LM ascent stage weight (staged)	10,729. lb
Descent stage propellant weight	17,207. lb
Descent engine thrust at the fixed throttle point	9712.5 lb (92.5% of design maximum)
Ascent engine thrust	3627. lb
Descent engine specific impulse	302. sec
Ascent engine specific impulse	303.4 sec

Maximum LM pitch rate	8°/sec
Altitude necessary so vertical rise is not required	25,000 ft
Vertical velocity necessary so vertical rise is not required	50 ft/sec

Miscellaneous Assumptions

For aborts during Hohmann transfer the LM becomes non-propulsive

For aborts during powered descent the LM achieves a predetermined orbit after abort

Change in ALO has negligible effect on the descent trajectory

Logic used to control vertical rise just after abort from powered descent taken from [2]

LM ascent after abort simulated with constant pitch rates instead of ascent guidance equations

Rendezvous from above and ahead

Burns previous to TPI are horizontal

Burns are impulsive (simulation of TPF by a single impulsive burn instead of using several midcourse and braking maneuvers causes an underestimation of the actual ΔV used by 10 to 20 ft/sec [4], which was not taken into account in the results of this memorandum)

Dispersions are not considered

Elapsed time from TPI to completion of crew transfer of 1.5 hr

Constraints on the Coelliptic Rendezvous Not Met*

Elevation of the LM below horizontal at TPI (in this study this angle varies from 28° to 30° depending on LM target orbit)	28.3°
Minimum time between burns (in this study this time was as low as 27 min)	34 min.

*The burns of the rendezvous could probably be adjusted slightly to meet these constraints.

APPENDIX B

EXPLANATION OF THE ΔV SURFACE SHAPE

In order to explain the shape of the ΔV surface in Figure 6 (LM target orbit apolune = 30 NM), for example, cross sections with constant time of abort are considered. In Figure A1 linear approximations of the orbital energy as a function of ALO for each orbit in the rescue 2 sequence up to the coelliptic orbit are sketched in order to show their relative magnitudes. Note that only the phasing orbit varies with the time of abort.

To change orbits energy is added or subtracted by making horizontal posigrade or retrograde burns expending ΔV, which varies smoothly and monotonically with energy change. To transfer from the lunar parking orbit to the coelliptic orbit several orbit changes are required so the total energy required for the rendezvous is the sum of the magnitudes of the energy changes plus the fixed energy for the TPI and TPF burns.

A discontinuity in the derivative of a function which is the absolute value of a smooth function occurs whenever the value of the smooth function passes through zero. In Figure A1 we see that the energy to change from the parking orbit to the transfer orbit passes through zero when the two orbits have the same energy (that is, they are the same orbit and no burn is required), so there is a discontinuity in the derivative of the ΔV surface at that ALO. Likewise, there is a discontinuity in the derivative when the energy of the transfer orbit equals the energy of the phasing orbit and when the energy of the phasing orbit is equal to the energy of the coelliptic orbit. Since the purpose of the rescue 2 burn is to transfer from the parking orbit to the correct differential height above the LM orbit perilune, if ALO = 60,000 ft + 10 NM = 19.9 NM, no rescue 2 burn is necessary; therefore, for all times of abort and all LM target orbit apolunes, there will be a discontinuity in the derivative of the ΔV surface at ALO = 19.9 NM. The positions of the other lines of discontinuity in the derivative of the ΔV surface shown in Figures 5 through 9 were found from graphs similar to Figure A1, but with orbital dimensions plotted.

Consider the specific case of abort at PDI + 400 sec. The points of discontinuity in the derivative are marked A, B and C denoting where the parking orbit energy is equal to the transfer orbit energy, where the phasing orbit energy is equal to the coelliptic orbit energy and where the transfer orbit energy is equal to the phasing orbit energy, respectively. For ALO lower than point A, energy must be increased from the parking orbit energy to the transfer orbit energy, increased to the phasing orbit energy and then decreased to the coelliptic orbit energy (as shown by the vectors on Figure A1). As ALO increases the total energy required for transfer decreases sharply. After point A the decrease is slower because the energy must be decreased to the transfer orbit energy before being increased to the phasing orbit energy. Between points B and C a minimum energy situation exists because no energy is wasted by having to transfer up to the phasing orbit energy then back down to the coelliptic energy. After point C total energy required starts to increase rapidly because one has to transfer down to the phasing orbit energy than back up to the coelliptic orbit energy. The reason that the total energy required for rendezvous is nearly constant between points B and C can be understood by considering the following. If we wished to transfer from the parking orbit to a circular orbit with altitude 19.9 NM, we would use the same transfer orbit as considered here, and the energy required to go from the parking orbit to the transfer orbit would be nearly the same as the energy to go from the transfer orbit to the 19.9 NM altitude circular orbit (that is, the magnitudes of vectors 1 and 2 in the figure are nearly equal). Therefore, the total energy to go from the parking oribt to the coelliptic orbit for all ALO between points B and C (the sum of the magnitudes of vectors 2, 3 and 4) is nearly the same as the energy difference between a 19.9 NM circular orbit and the coelliptic orbit (the sum of the magnitudes of vectors 1, 3 and 4), which is a constant.

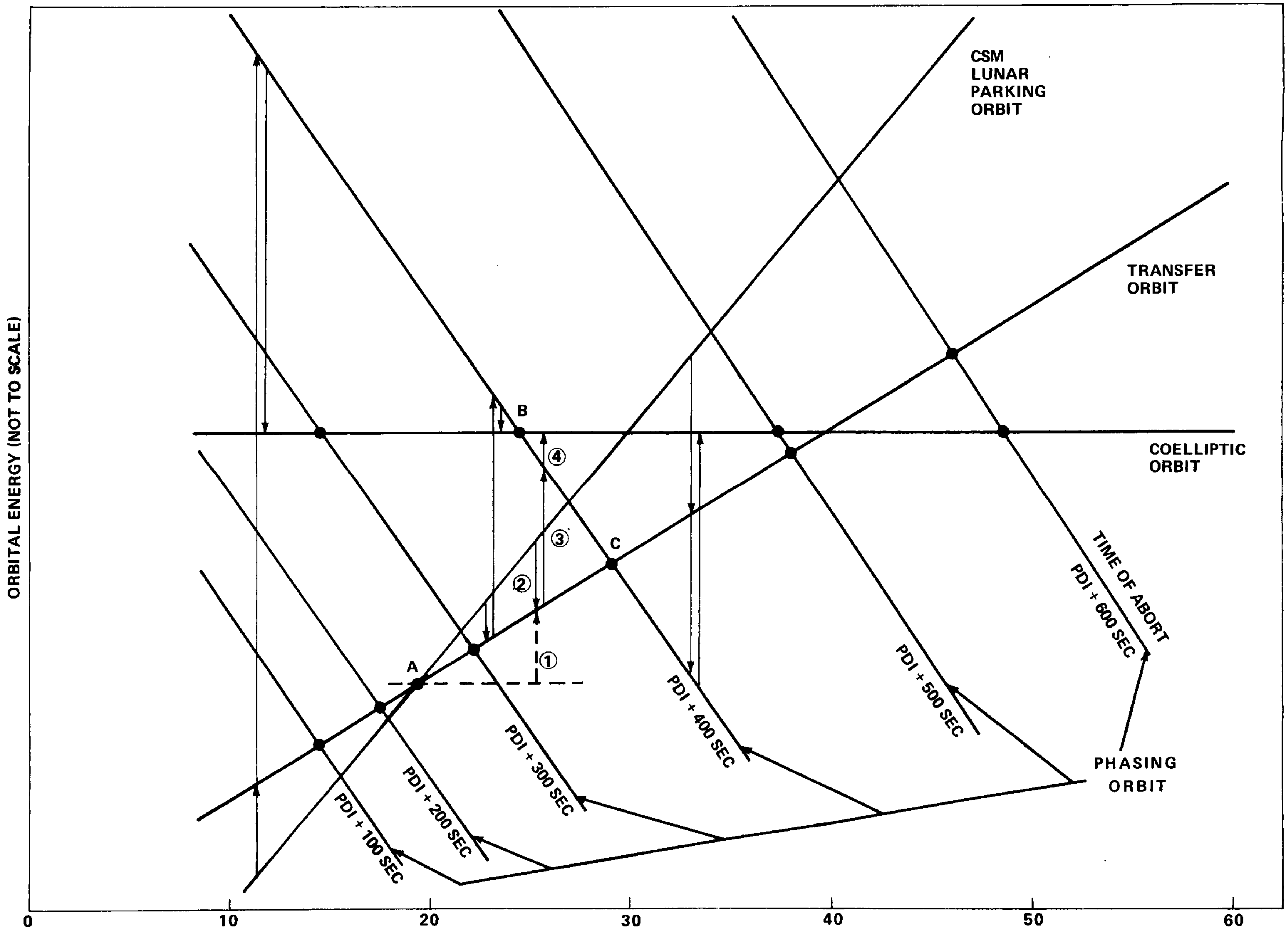

FIGURE A1 - SKETCH OF ENERGY OF ORBITS IN CSM RESCUE 2 RENDEZVOUS
LM TARGET ORBIT 60,000 FT x 30 NM

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